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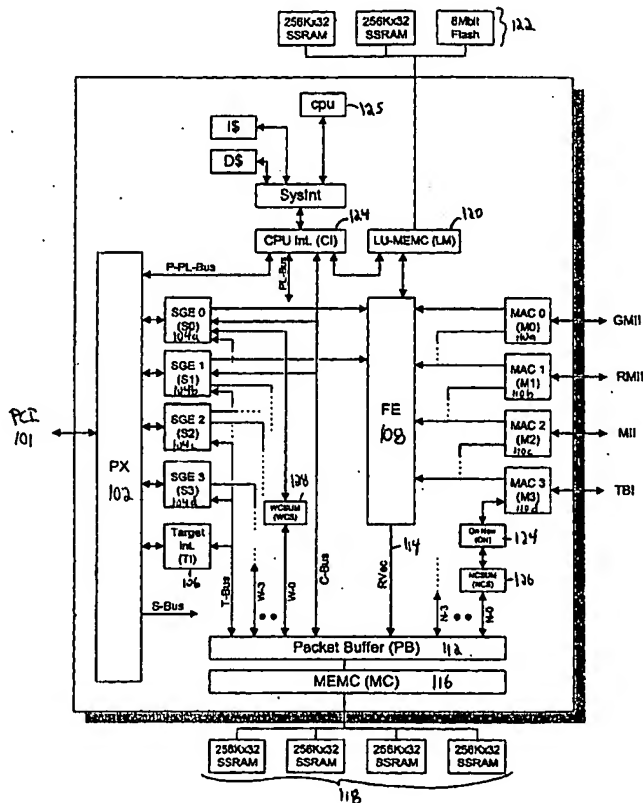
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[Continued on next page]

(54) Title: MULTI-PURPOSE SWITCHING NETWORK INTERFACE CONTROLLER



(57) Abstract: A network interface controller includes a plurality of scatter gather circuits (104a-104d) connectable to a host via a bus (101). A packet buffer (112) is configured for communication with the scatter gather circuits (104a-104d). A plurality of access circuits (110a-110d) are configured to access external network connections. An optional forwarding engine (108) is selectable to generate routing information corresponding to data received via the access circuits (110a-110d) and to provide the routing information to the packet buffer (112).



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NE, SN, TD, TG).

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MULTI-PURPOSE SWITCHING NETWORK INTERFACE CONTROLLER

TECHNICAL FIELD

The present invention is in the field of network interface controllers and, in particular, is related to a switching network interface controller that is configurable for use in a variety of different networking configurations.

BACKGROUND

There are a variety of networking applications for which, conventionally, various specialized hardware is available. It would be desirable to have a network interface controller solution that is flexibly configured for use in these various applications.

SUMMARY

A reconfigurable network interface controller circuit is provided for various networking operations. The circuit is scalable, and provides for redundancy in such networking operations.

The network interface controller includes a plurality of scatter gather circuits connectable to a host via a bus. A packet buffer is configured for communication with the scatter gather circuits. A plurality of access circuits are configured to access external network connections. An optional forwarding engine is selectable to generate routing information corresponding to data received via the access circuits and to provide the routing information to the packet buffer.

BRIEF DESCRIPTION OF FIGURES

Figure 1 schematically illustrates an example multipurpose network interface controller circuit.

Figures 2A and 2B illustrate the Figure 1 circuit in a network interface controller configuration.

Figures 3A and 3B illustrate the Figure 1 circuit in a switch configuration.

Figure 4 illustrate the Figure 1 circuit in a hybrid configuration.

Figure 5 illustrates the Figure 1 circuit in a network processor configuration.

DETAILED DESCRIPTION

Turning now to Figure 1, an example configurable network interface controller circuit 100 is described. In some embodiments, the Figure 1 network interface controller circuit is implemented in an application specific integrated circuit (ASIC), such as a field-programmable gate array (FPGA). In one example, the circuit is configurable to implement applications such as:

- Multi-Channel Ethernet NIC Controller
- L2/L3 Ethernet Switch
- System Controller
- 10 • SOHO Router
- Network Processor

The various blocks of the Figure 1 example are now summarized.

PCI-X CORE (PX 102)

This is a standard quad-function PCI-X core, with 4 identical Master interfaces to SGE's 104a through 104d, and one target interface TI 106. This block in addition houses the Serial ROM interface logic.

Forwarding Engine (FE 108)

This module makes routing decisions based on a vector that it receives from the MAC 110 or the SGE 104 modules. The results of the routing decisions are conveyed to the packet buffer PB 112 via the Route Vector bus 114.

MAC (Mn 110)

This is a 10/100/1000 MAC module. In one example, this module includes VLAN Tag and Station Address logic (which are normally disabled in the presence of a Forwarding Engine).

25 *Packet Buffer (PB 112)*

This is a general purpose queuing engine core switch fabric, that allows management of arbitrary sized packets. A particular example of the PB 112 is described in U.S. Provisional Patent Application No. 60/283,285 filed April 11, 2001 and incorporated herein by reference in its entirety.

Memory Controller (MC 116)

This is a generic memory controller that can control, for example, SSRAM memories 118.

Lookup Memory Controller (LM 120)

- 5 This is an SSRAM only memory controller that provides a path to an external memory 122 (e.g., for a forwarding table and/or instruction memory).

CPU Interface (CI 124)

- 10 This module is a collection of muxes and base addresses that switches various busses and manages the address map of an on-board processor 125. This module decodes the PL-Bus regions and generates chip selects to various modules.

Scatter Gather Engine (SGn 104)

This module handles the Scatter Gather operation in a NIC mode, provides a path to the packet buffer 112 from PX 102 in the Switch mode, and provides a path to the packet buffer 112 from the CPU 125 in the System Controller mode.

- 15 *Wake up, On Now Logic (ON 124)*

This module implements power management functions.

Narrow Checksum (NC 126)

This module calculates the TCP/IP/HTTP/UDP checksums and provides the result to the packet buffer 112 upon completion of a frame arriving from the MAC 110.

- 20 *Wide Checksum (WC)*

This module calculates the TCP/IP/HTTP/UDP checksums and provides the result to the packet buffer PB 112 upon the completion of a frame as it is arriving from the PCI bus 101 via the PX 102.

- 25 In all modes of the operation (NIC, Switch, etc.), the data is pushed to the SGE 104 by the packet buffer 112 and to the packet buffer 112 by the SGE 104.

- 30 Clocking within the Figure 1 example is now described. Specifically, the components of the Figure 1 example operate in three different clock domains. These clock domains include the core clock domain (which includes the on-board CPU 125 and the memory interfaces (LM 120 and MEMC 116); the MAC 110 clock domains (which, in

some examples, includes several actual clock regimes); and the PCI-X 101 clock domain. In some examples, no phase lock loops are employed.

In cases where the Figure 1 example is an FPGA as opposed to an ASIC, the FPGA clocking is the same as the ASIC clocking except for the MAC clock section. Further,
5 some IO delay lines are inherent to the FPGA IO pads, and are explicitly built in the ASIC configuration.

In reset, all clock domains are synchronized to the PCI-X clock domain. The PHY chips can be reset individually. In addition, soft reset resources allow the local resetting of the Figure 1 circuitry by the local processor 125 under control of local firmware.

10 In accordance with one example, the Figure 1 circuit is operable in at least four different modes by reconfiguring the operation of the various modules. Each of these four modes of operation are now described. In the description, the Receive and Transmit nomenclatures are always with reference to the wire (i.e., receive from the wire and transmit to the wire) unless otherwise specified.

15 The NIC operation mode is now discussed with reference to Figures 2A and 2B. In general, the NIC operation mode is a relatively simple mode of operation of the Figure 1 example circuit. A simplified block diagram of the NIC mode is represented in Figures 2A and 2B. In this mode, the on-chip processor 124, the forwarding engine 108 and the associated secondary memory 122 are not used (and, in fact, need not be even populated in
20 the ASIC/FPGA) and, thus, are shown as "grayed out" in Figure 2B. Various NIC operation mode operations are now described.

NIC Receive

In the NIC receive operation, data is received from the MAC 110, through the N-Bus, and stored in the PB 112 using, for example, the paging hardware of the packet buffer
25 PB 112. The Rvec is determined in one example using a stub model, for the packet buffer PB 112 to determine from which queue it should push the data out. Once the data is completely stored in the appropriate queues of the packet buffer, it is then pushed to the appropriate Scatter Gather Engine 104. While transiting on the N-Bus, checksums are calculated on the incoming data from the MAC 110 by the NCS 126 and stored into the
30 packet buffer PB 112. In one example, the checksum 110 storage is accomplished by strobing a payload (including the checksum) to the packet buffer PB 112 following the last element of the data being stored. The stored data is then transferred into the host memory

from the PB 112 by the Scatter Gather Engine 104 (via the PX 102 and the PCI-X 101). In this mode of operation, the packet buffer PB 112 does not perform any broadcast or multicast operations and, as such, looks substantially like an external FIFO per channel.

NIC Transmit

5 In the NIC transmit mode, data is gathered from the host memory (via the PCI-X 101 and PX 102) by the appropriate SGE 104 and pushed to the packet buffer PB 112. While transiting the W-Bus, checksums are calculated on the data by the WCS 128 and delivered to the packet buffer PB 112 by strobing a payload (including the checksum) into the packet buffer PB 112 following storage of the last element of data. Once the packet is
10 completely stored in the packet buffer PB 112, the packet is forwarded onto the N-Bus to the appropriate MAC 110.

NIC Fail Over

 The link fail over is handled entirely in software.

NIC Multicast and Broadcast

15 These features are handled entirely in software.

NIC Flow Control

 In the receive direction, once the descriptor queue of a TAP in the packet buffer PB 112 goes over a high water mark, a signal is asserted to the corresponding MAC 110 to cause the MAC 110 to generate flow control signals to its link partner. Depending on the
20 MAC configuration, the traffic resumes either after a fixed amount of time or after the queue in the packet buffer PB 112 has dropped below the low water mark, the occurrence of which is also transmitted to the MAC 110. In the transmit direction, once the queue for the TAP, in the packet buffer, becomes full and data "backs up" into an SGE 104, the transmit function of the packet buffer 112 simply stops. In both directions, once the SGE
25 104 runs out of resources such as free lists or transmit buffers, traffic simply stops.

 The switch operation mode is now described with reference to Figures 3A and 3B. In the switch configuration, the Figure 1 example circuit employs the local forwarding engine FE 108 to make routing decisions for each packet in each direction. A given packet
30 is examined once upon arrival to the source node and once upon exiting the destination node. The local processor CPU 125 is used for management purposes.

The switch backplane may be thought of as a virtual backplane. That is, the switch backplane includes multiple virtual channels on top of the PCI bus 101. Each virtual channel includes a scatter gather engine SGE 104 performing DMA writes to a reserved range of addresses in the host memory. That range of address is programmed into the receiving node's PCI base address register. Therefore, each pairing of the base address value programmed into a node's PCI base address register and the value programmed into another node's scatter gather engine 104 receive DMA address register configures a virtual channel. Each node is effectively a quad-function PCI device and hence has 4 memory base addresses, thus allowing 4 virtual full-duplex links to a node. This virtual back-plane of one example uses three base addresses, leaving the fourth one, corresponding to the node number of the device, unused.

In the switch mode of operation, the Scatter Gather Engine 104 does not do any linked list operations and simply pushes the data as consecutive data elements to the PCI 101. The data arriving from the PCI 101 is received on the PCI's target interface 106 which is then muxed to the appropriate SGE 104. The receive DMA address restarts at the base address at the start of every packet and the lower bits of the address are used to determine the length of a packet. Upper bits of the address, while still within the address range, are used to transfer additional information to the receiver. Each base address range is 256 Mbytes (28 bits). The largest packet that the switch handles is 64Kbytes (16 bits), allowing 12 bits of payload (e.g., sequence numbers, etc.). Each node can be conceptualized, in some instances, as either a Source Node or a Destination Node. Source Node is the node where a packet initially comes into the system (via the Source Port), and Destination Node is the node through which the packet leaves the switch.

As data arrives from the MAC 110, the MAC 110 generates a long vector comprised of the DA, SA, VLAN, QoS fields of the incoming packet. This vector is then submitted to the forwarding engine FE 108. The packet then bypasses the checksum 126 and wake up 124 blocks before being written into the packet buffer PB 112. By this time, the forwarding engine 108 computes a routing vector 114 which is provided to the packet buffer 112 for the packet buffer 112 to place on the appropriate destination queue. In one example, a limit of 16 clocks is placed on the forwarding engine 108 for the lookup time per minimum sized packet (64 bytes). During this time, the forwarding engine 108 completes two lookups and a conditional learn operation.

Once the packet is fully stored in the packet buffer 112, it is pushed out one of the W-Buses to the SGE module 104. The SGE module 104 -- which operates as a pass through in the switch configuration -- simply pushes the data out to the node that was indicated by the forwarding engine 108. The packet eventually appears on the target
5 interface (T-Bus) of the destination node's PCI bus 101. Once the data arrives from the PCI bus 101 on the T-Bus of a destination node, the target interface 106 of the destination node routes the packet to the packet buffer 112 of the destination node. Meanwhile, the forwarding engine 108 computes a routing vector 114 for the packet and submits the routing vector 114 to the packet buffer 112.

10 Switch multicast and broadcast are handled in the forwarding engine 108. In case of a multicast or broadcast packet, the result is flagged to the packet buffer via a routing vector with multiple bits set.

In one example, the packet buffer 112 and the forwarding engine 108 can each pipeline two messages, to absorb the latency of the forwarding engine 108. The SGE 104
15 use flow control PIO writes to its link partner SGE to control the rate of the switch backplane traffic.

The hybrid mode of operation is now described with reference to Figure 4. In the hybrid mode of operation, the Figure 1 example circuit acts as a 4-port switch combined with a up to a 4-port NIC. The Figure 1 example circuit can "own" up to eight MAC
20 addresses, four for its switched ports and up to four for its embedded NIC ports. The hybrid mode of operation is handled in the forwarding engine 108. Although the architecture allows for more, in some examples, the forwarding engine 108 has only enough bandwidth for a single port NIC. Power management logic is used in the hybrid mode to detect "magic packets," etc. and to generate appropriate power management events.

25 Once a packet arrives from the MAC 110 ("receive event"), the received packet is submitted to the forwarding engine 108. The received packet is concurrently written into the packet buffer 112 followed by checksum information. The Rvec 114 from the forwarding engine 108 indicates if the packet should be switched out of a port (via one of the N-Buses) or delivered to the host (via a W-Bus). Data received into the SGE 104 from
30 the packet buffer 112 is typically delivered to the host.

For transmit, the data to be transmitted is normally gathered from the host memory into the packet buffer 112. However, the SGE 104 also submits the packet to the forwarding engine 108. The forwarding engine 108 in turn indicates to the packet buffer

112 onto which queue of the packet buffer 112 to place the packet. The checksums are calculated in this path. Although unlikely, one NIC port may wish to send a packet to another NIC port.

In the "system controller" mode of operation, any external host adapter is leveraged for interfacing to other protocols (e.g., SCSI, USB, SONET, USB, etc.). The NIC appear as a PC to the external host adapters. As such, the Figure 1 example circuit provides a high bandwidth path to the local packet buffer 112. Further, a section of the packet buffer 112 is allocated as simple passive memory for use by the external host adapters. The external host adapters use this area to scatter and gather their traffic into the local memory 118. The processor 125 can access this data via the C-Bus path. Thus, in this mode, the Figure 1 circuit is functioning as a system controller integrated with a processor.

In the network processor mode of operation, represented in Figure 5, firmware effectively "visits" every packet at the wire speed while relieving some of the overhead of packet processing. All the packet processing may then be performed via the firmware. This mode of operation can be thought of as a superset of the system controller mode of operation. In this mode of operation, it is generally desired to transfer data from one MAC 110 to another MAC 110 or to an external host adapter once the processor has had an opportunity to read and write portions of the packet. Once the packet is modified, the Figure 1 circuit recomputes the checksums. In this configuration, the SGE modules 104 are used by the local processor 125 to access the packets via the queueing system. Thus, the head of the W-Bus FIFO in the SGE module 104 is read by the processor 125 via C-Bus and it is written to via C-Bus.

The network processor receive operation is now described. As packets arrive from the MAC 110, the checksums for the packets are computed (126) and the packets are written into the packet buffer 112. The packet buffer 112 operates in the NIC mode in this case. That is, there is effectively a hard path between N-Bus-0 to W-Bus-0, etc. The received data is pushed out to the respective SGE 104 via the respective W-Bus. Once the SGE 104 senses the presence of new data, it interrupts the local processor 125. The processor 125 then performs burst reads of SGE's 104 W-Bus receive FIFO into the data cache of the processor 125. Once the processor 125 has examined and rewritten the data, the processor 125 scatters the data into a portion of the packet buffer 112 not used for queuing. The data is then gathered by the external host adapter and consumed by the host adapter. Optionally, the data from the local processor 125 is burst written into the SGE's

104 transmit W-Bus FIFO. The checksum is computed (128) on this data by the Figure 1 example circuit before being written into the packet buffer 112. Further, the routing vector from the first element of data is retrieved and submitted to forwarding engine 108 for multiplexing onto the Rvec bus 114 so as to place the packet on the desired N-Bus or W-Bus queue in the PB 112.

The network processor transmit operation is now described. When a packet is to be transmitted to the wire by an external host adapter, the packet is first scattered into the local memory 118 by the external host adapter. The packet is then read by the local processor 125 via the C-Bus. Once the local processor 125 has examined and rewritten the packet, the local processor 125 burst writes the packets along with a routing vector 114 into the transmit W-Bus queue of the SGE 104. The checksum on the packet is then computed (128) and the packet is forwarded to the N-Bus or W-Bus. If the packet to be transmitted is coming from another port of the same instantiation of the Figure 1 circuit, the packet is first received by the local processor 125 and is then burst written into the SGE 104 along with a routing vector.

What is claimed is:

1. A network interface controller, comprising:
 - a plurality of scatter gather circuits connectable to a host via a bus;
 - a packet buffer configured for communication with the scatter gather circuits;
 - 5 a plurality of access circuits configured to access external network connections; and
 - an optional forwarding engine selectable to generate routing information
- corresponding to data received via the access circuits and to provide the routing information to the packet buffer.

AMENDED CLAIMS

[received by the International Bureau on 18 September 2002 (18.09.02);
new claims 2-11 added; remaining claims unchanged]

1. A network interface controller, comprising:
a plurality of scatter gather circuits connectable to a host via a bus;
a packet buffer configured for communication with the scatter gather circuits;
a plurality of access circuits configured to access external network connections; and
an optional forwarding engine selectable to generate routing information
corresponding to data received via the access circuits and to provide the routing
information to the packet buffer.
2. The network interface controller of Claim 1, configured such that:
the forwarding engine is inactive;
the packet buffer and access circuits are configured for data communication
therebetween; and
the packet buffer and scatter gather engines are configured for data communication
therebetween;
whereby the network interface controller is configured to a network interface-
controller mode of operation.
3. The network interface controller of Claim 2, wherein:
the packet buffer and access circuits being configured for data communication
therebetween includes the packet buffer being configured to utilize paging hardware
thereof for receiving the data from the access circuits.
4. The network interface controller of Claim 3, wherein:
the packet buffer and access circuits being configured for data communication
therebetween includes the packet buffer being configured to selectively cause the access
circuits to assert flow control signals to corresponding link partners.
5. The network interface controller of Claim 2, wherein:
the packet buffer and access circuits being configured for data communication
therebetween includes the packet buffer being configured to determine that it has received a
complete data packet and to transmit the received complete data packet to an appropriate
access circuit.

6. The network interface controller of Claim 1, wherein:
the scatter gather engines are configured for pass-through data communication
between the packet buffer and external bus circuitry;
5 the forwarding engine is configured to route the data communication between the
access circuits and the packet buffer,
whereby the network interface controller is configured in a switch mode of
operation.
- 10 7. The network interface controller of Claim 6, wherein:
the scatter gather engines are configured to:
perform DMA writes of the pass-through data to a host memory of the
network interface controller; and
perform DMA reads of the pass-through data from a host memory of another
15 network controller.
8. The network interface controller of Claim 6, wherein:
the forwarding engine being configured to route the data communication between
the access circuits and the packet buffer comprises computing a routing vector based on the
20 data being communicated and providing the routing vector to the packet buffer.
9. The network interface controller of Claim 8, wherein:
the packet buffer processes the routing vectors to control the inflow of data to and
outflow of data from the packet buffer.
25
10. The network interface controller of Claim 1, wherein:
the forwarding engine is configured to process receive data from the access circuits
and to generate receive routing information therefrom; and
the packet buffer is configured to process the receive routing information in order to
30 selectively provide the receive data to an access circuit or to a scatter gather engine.
11. The network interface controller of Claim 1, wherein:

the forwarding engine is configured to process transmit data from the scatter gather engines and to generate transmit routing information therefore; and

the packet buffer is configured to process the transmit routing information and to process the transmit data based thereupon.

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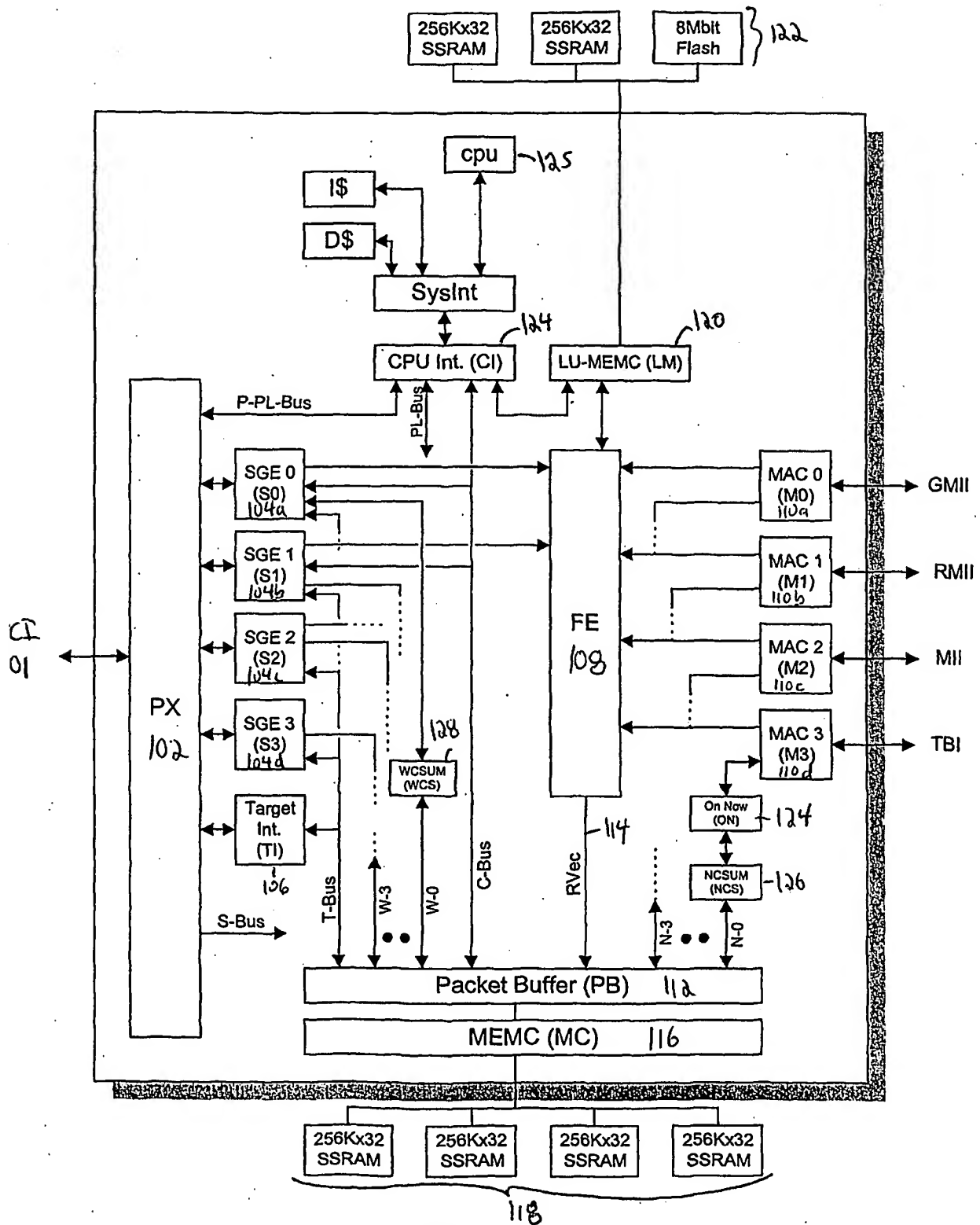


Figure 1

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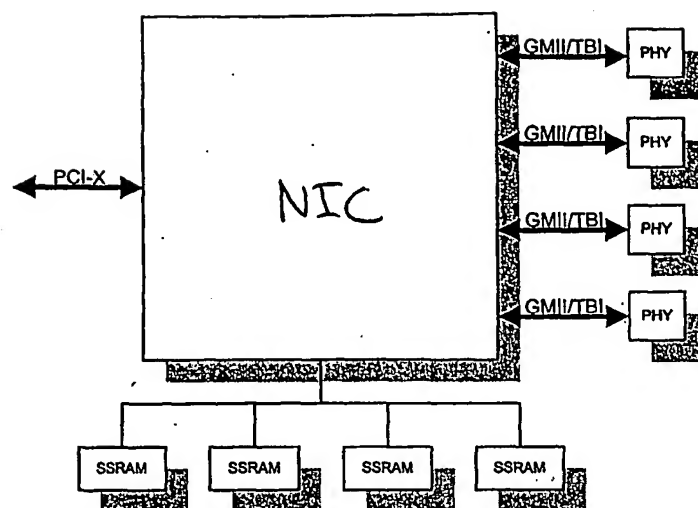


Figure 2A

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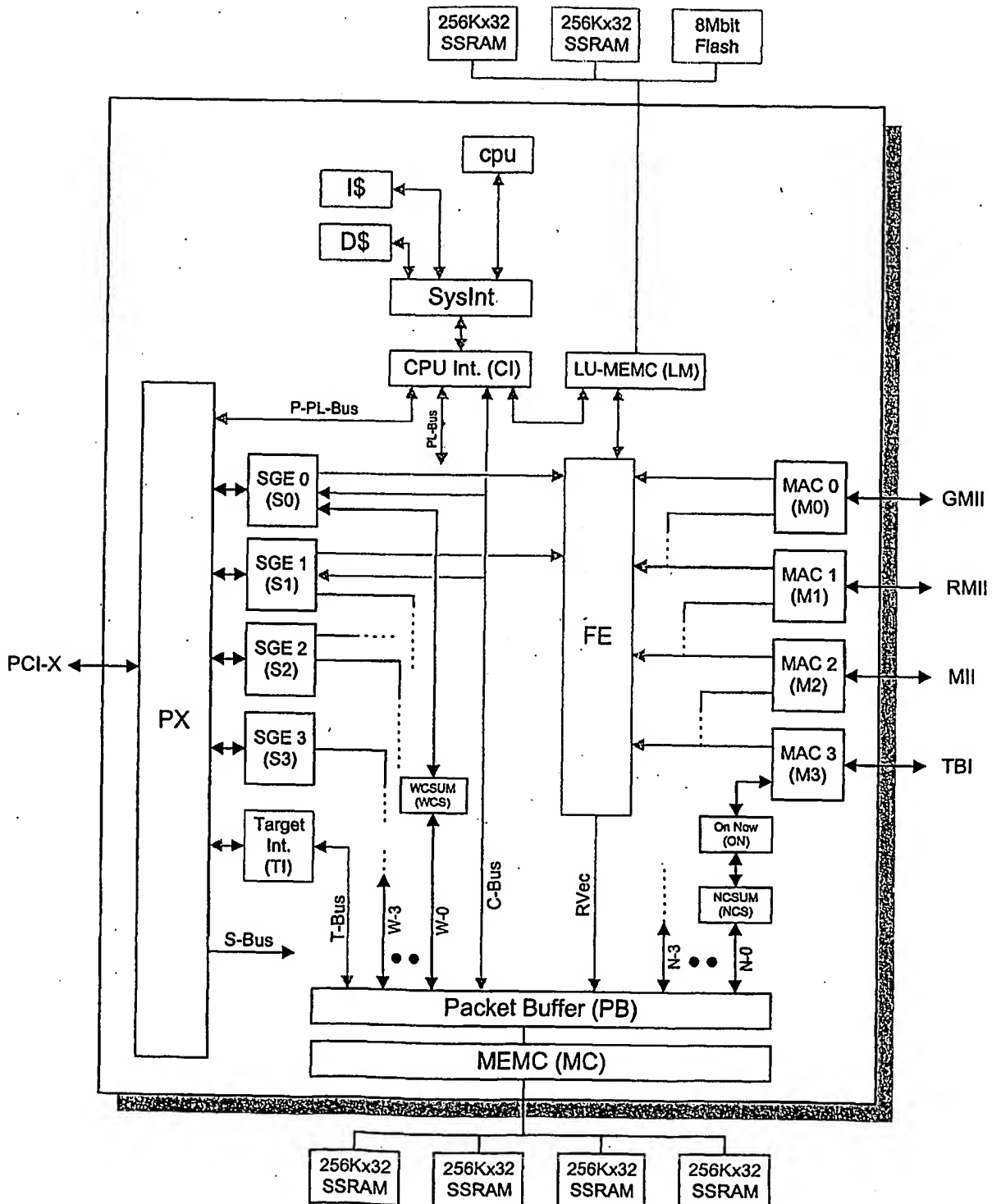


Figure 2B

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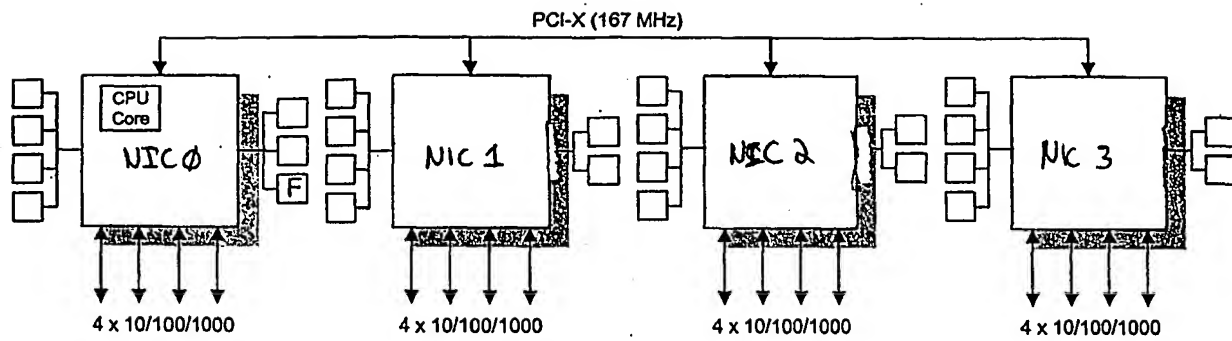


Figure 3A

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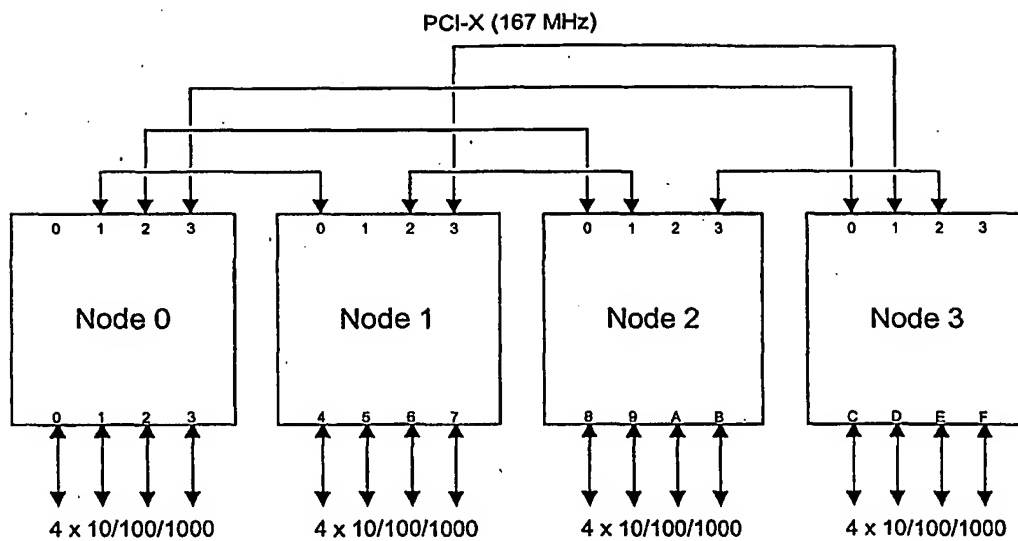


Figure 3B

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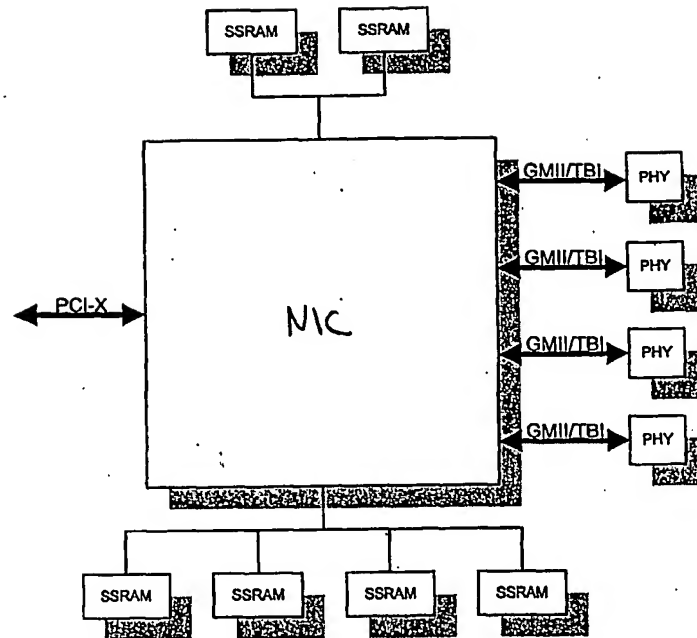


Figure 4

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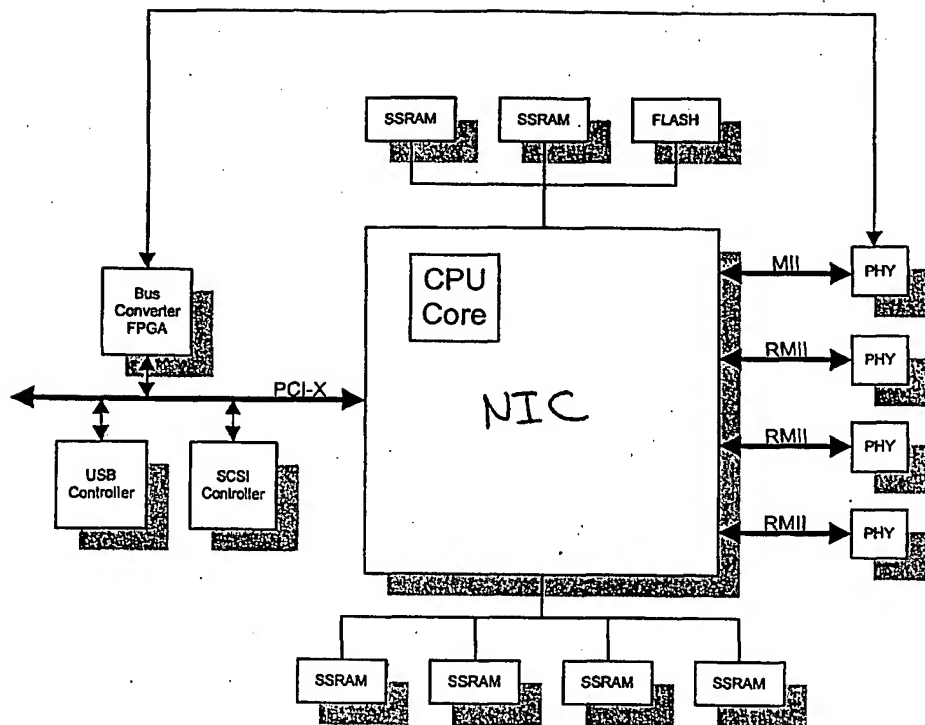


Figure 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/12679**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : G06F 13/00

US CL : 709/250

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 709/200,213,217,218,250; 711/112,200,201,207

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WEST:

search terms: ((scatter ajd1 gather\$) or "scatter-gather") and network\$

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,E	US 6,397,316 B2 (FESAS, JR.) 28 May 2002 see Abstract, figures 1-9, col. 1 (lines 18 and 60), col. 2 (lines 8-9, 32-25, and 64-et seq.).	1
A	US 5,497,476 A (OLDFIELD et al.) 05 MARCH 1996 see Abstract, figures 1-2, and col. 2 (line 10-et seq.).	1



Further documents are listed in the continuation of Box C.



See patent family annex.

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